A real-time beam monitoring system for highly dynamic irradiations in scanned proton therapy

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PROSCAN
Proton therapy beamlines at the Paul Scherrer Institute
Latest developments
Fast irradiations on Gantry 2

Clinical example

- liver tumor (460 cm$^3$)
- single field (0.6 Gy)
Latest developments
Fast irradiations on Gantry 2

Clinical example
- liver tumor (460 cm³)
- single field (0.6 Gy)

conventional 52 sec.  accelerated 26 sec.
Latest developments
Fast irradiations on Gantry 2

Clinical example
- liver tumor (460 cm$^3$)
- single field (0.6 Gy)

conventional 52 sec.
accelerated 26 sec.

treating patients since Nov. 2011
not treating patients yet
speed
Conventional irradiations on Gantry 2

→ ‘Step-and-shoot’ irradiations

cyclotron

proton beam
degraded (Δz)
scanner magnets (Δx, Δy)
beam monitors
tumor
Conventional irradiations on Gantry 2

→ ‘Step-and-shoot’ irradiations

- Cyclotron
- Proton beam
- Degrader ($\Delta z$)
- Scanner magnets ($\Delta x, \Delta y$)
- Beam monitors
- Tumor
Conventional irradiations on Gantry 2

→ ‘Step-and-shoot’ irradiations
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'Step-and-shoot' irradiations
‘Step-and-shoot’ irradiations

- Conventional irradiations on Gantry 2
- Cyclotron
- Tumor beam monitors (Δx, Δy)
- Degraded (Δz)
- Proton beam
- Scanner magnets
- Beam irradiations

→ 'Step-and-shoot' irradiations
Conventional irradiations on Gantry 2

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→ ‘Step-and-shoot’ irradiations

← Cyclic monitoring (after every spot)

• position within tolerance (± 1.5 mm)
Conventional irradiations on Gantry 2

→ ‘Step-and-shoot’ irradiations

← Cyclic monitoring (after every spot)

• position within tolerance (± 1.5 mm)

• # protons within tolerance (± 2%)
Conventional irradiations on Gantry 2

→ ‘Step-and-shoot’ irradiations

← Cyclic monitoring (after every spot)
  • position within tolerance (± 1.5 mm)
  • # protons within tolerance (± 2%)

DRAWBACK
rather ‘slow’
Accelerated irradiations on Gantry 2

→ Continuous irradiations

- Cyclotron
- Proton beam
- Degrader ($\Delta z$)
- Scanner magnets ($\Delta x, \Delta y$)
- Beam monitors
- Tumor
Continuous irradiations

Accelerated irradiations on Gantry 2
Continuous irradiations
Accelerated irradiations on Gantry 2

→ Continuous irradiations
Accelerated irradiations on Gantry 2

→ **Continuous** irradiations

- **cyclotron**
- **proton beam**
- **degrader (Δz)**
- **scanner magnets (Δx, Δy)**
- **beam monitors**
- **tumor**
→ **Continuous** irradiations

← **Real-time** monitoring (every 10 µs)

- position within tolerance (± 1.5 mm)
Accelerated irradiations on Gantry 2

→ **Continuous** irradiations

← **Real-time** monitoring (every 10 µs)

- position within tolerance (± 1.5 mm)
- current within tolerance (± 5%)
Accelerated irradiations on Gantry 2

→ Continuous irradiations

← Real-time monitoring (every 10 µs)
  • position within tolerance (± 1.5 mm)
  • current within tolerance (± 5%)

CHALLENGE
highly dynamic
safety
Independent beam delivery and monitoring

- **Delivery system**
  - (PowerPC ↔ FPGA)
  - Actuators
    - Accelerator
    - Scanner magnets
  - Monitors
    - Hall probes
    - Ionization chambers

- **Monitoring system**
  - (PowerPC ↔ FPGA)
  - Output
    - Position
    - Current
Position and current control based on trajectory tables:

<table>
<thead>
<tr>
<th>time [ms]</th>
<th>position [cm]</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>-5</td>
</tr>
<tr>
<td>40</td>
<td>-3</td>
</tr>
<tr>
<td>60</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>+2</td>
</tr>
<tr>
<td>150</td>
<td>+3</td>
</tr>
<tr>
<td>200</td>
<td>+5</td>
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</table>
Response of our test system to tolerance violations
Position and current control based on trajectory tables:

**beam current**

<table>
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<tr>
<th>time [ms]</th>
<th>current [nA]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>1</td>
<td>0.3</td>
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<tr>
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</tr>
<tr>
<td>199</td>
<td>0.2</td>
</tr>
<tr>
<td>200</td>
<td>0.0</td>
</tr>
</tbody>
</table>

![Graph showing beam current over time](image)

- **ionization chamber**
Response of our test system to tolerance violations
Beam current interlock

Response of our test system to tolerance violations

300 µs
• First implementation of real-time beam monitoring on a proton therapy beamline

**position:** indirect supervision via Hall probes in beam-scanning magnets

**current:** direct supervision via ionization chambers at the end of the beamline

• Identical monitoring devices for conventional and accelerated scanning mode

• **Ongoing:** testing of error scenarios and interlock resumption strategies
Thank you for your attention!

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